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Mobility Management for Vehicular User Equipment in LTE/ Mobile Femtocell Networks

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ABSTRACT

Vehicular User Equipment (UE) performance during mobility faces two issues relating to signalling and transmission, namely Handover (HO) and link adaptation. This paper shows that both processes are experiencing degradation during mobility and that vehicular UEs suffer from call drops and loss of connections. Therefore, this work presents an effective technique using Mobile-Femtos to improve vehicular UEs' HO process and link quality. Results show that vehicular UEs attached to a Mobile-Femto achieved better signalling and Link Ergodic capacity and as a consequence the outage probability was reduced. The achieved results indicated that deploying Mobile-Femtos under 25dB Vehicular Penetration Loss (VPL) has improved the vehicular UE Link Ergodic capacity by 1% and reduced the signal outage probability by 1.8% compared to the eNB direct transmission. Consequently, Drop Calls Probability (DCP) and Block Calls Probability (BCP) have been reduced by 7% and 14% respectively compared to the direct transmission from the eNB.

KEYWORDS

LTE, Mobile Femtocell, Penertration Loss, Vehicular User Equipment, Outage Probability, Ergodic capacity, Drop Calls Probability, Block Calls Probability

INTRODUCTION

In LTE heterogeneous networks, there is a large number of small cells such as Microcells, Pico-cells or Femtocells (Mokhtar et al., 2012) camped on the coverage of larger cells like Macrocell as Figure 1 shows in the Appendix section (Heath, 2015).

This is because, at the cell-edges the Macrocell coverage may not be as strong as expected due to several factors on top of them path-loss, penetration loss and different types of fading. Therefore, the small cells are deployed at the cell-edges to improve the Macrocells coverage and capacity. They are also deployed inside the Macrocells in hotspots to increase the possibility of traffic offloading from larger cells to small ones (Bhat et al., 2012).

However, in the new cell topology of an LTE system, mobility is challenging due to the changes in the cell size and radio channel conditions each time the UE connects to a new cell. The UE may pass through the deployed cells with different speeds and this affects the robustness of the HO process in some situations where there is low Signal-to-Interference -plus-Noise Ratio (SINR) and high interference between the small cells (Ain Amirrudin et al., 2014).

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Thus, the UEs' main concern here is to receive the desired signal in terms of strength and quality. Those UEs have the option to connect to any cell – large or small – when the signal of this cell meets the selection criteria of the evolved NodeB (eNB). Another important consideration is the UE's speed when passing cross or close to small cells (Lorca et al., 2013). The high UEs speed makes it impossible for those vehicular UEs to have long connection with the serving small cells outside the vehicle as this may increase the number of unnecessary HOs because the number of HOs is inversely proportional to the cell size. High number of HOs implies that there is an increase in the signalling load, and this has a negative impact on the achieved throughput, as there is no data transmission during the HO period (Raheem et al., 2017).

Therefore, improving the vehicular UEs HO is one of the key procedures for ensuring that those UEs can move freely through the network while still being connected and bestowed quality services. Hence, Mobile-Femtos have been proposed to serve those vehicular UEs and improve the HO procedure by reducing the unnecessary number of HOs. Besides the high mobility aspect, the challenge here is handing over the Mobile-Femto itself when it leaves the Macrocell coverage to another Macrocell. The HO process here is not for regular UEs, it is for handing over a Base station (BS) with group of UEs e.g. bus passengers. Thus, several criteria need to be considered in this case like the bus/(Mobile-Femto) direction, backhaul link adaption between Macrocell and Mobile-Femto, channel availability, Bandwidth (BW) availability and Physical Resource Blocks (PRBs) availability in the target Macrocell. In the light of this, an optimised HO algorithm has been proposed to achieve the required network performance by mitigating the vehicular UEs outage probability and the probability of dropping/blocking calls in LTE vehicular network as well as enhancing the Link Ergodic capacity.

RELATED WORK

In an LTE system, the mobility management procedures such as HO and cell reselection are becoming more complex due to the dense deployment of different type of cells. Many studies have examined the mobility robustness and HO issues in heterogeneous networks. Researchers have focused on different topics such as signal strength during HO, interference, SINR, cells' properties, UEs positioning, outage probability, drop and block calls probabilities.

Guohua (2013) proposed mobility robustness optimisation scheme based on exploiting measurement reports such as link quality, SINR, UE's position and direction. The aim of the study was to find the best target cell by updating the HO trigger mechanism after considering the SINR parameter. While in Peng (2012), they proposed two schemes to improve the HO performance during the process of Pico-cells leaving and attaching. The idea is to perform the HO from a small to a large cell and vice versa. It is worth noting that the above were based on fixed BSs where the UEs were vehicular. As result, an increased number of unnecessary HOs which will lead to an increased number of dropped calls.

On the other hand, Guidolin (2014) modelled the UE state during the HO process to find the optimal HO criterion with consideration given to path-loss, channel outage and fading propagation. This study monitored the SINR changes along the UE's trajectory. If the SINR decreases below the threshold, the UE switches off its cell and connects to a new one. While in (Lopze-perez et al., 2012), the researchers proposed a technique based on the Inter Cell Interference Coordination (ICIC). In this technique a co-channel scenario assumed between Pico-cells and Macrocells. As a result, low and high mobility UEs allocated the blank resource blocks in the Pico-cell and Macrocell respectively. However, this technique may not work as efficient as required in high penetration loss and path-loss areas, e.g. for LTE cell-edge vehicular UEs. This is because assigning those UEs to be served by the Macrocell, can increase the outage and drop calls probabilities due to the high VPL of direct signals and the extra burden on the eNB to maintain their connection.

More studies considered the HO between the Fixed-Femto and the eNB in LTE network. In (Xu, 2010) the authors investigated the HO between the Macrocell and the Fixed-Femto layers. This study is based on the UE's state and the SINR, taking into account the power difference between the two layers. Instead of relying on the Received Signal Strength (RSS) as in a conventional HO, the UE hands off to the cell of higher SINR. While (Moon et al., 2010), has suggested a "novel decision algorithm" to manage the mobility of the UE towards the Fixed-Femto. In this algorithm, the Femtocell's RRS value should be greater than the set threshold in order to guarantee a good quality of connection.

Similarly, the authors in (Saied et al., 2012) proposed an analytical model for mobile UE connection probability in Femto-Macro cellular networks. The aim was to improve the performance of the connectivity probability in terms of the communication range when Macro UEs at the boundary of the Macrocell and the Fixed-Femto at the same time.

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The obtained results showed an improvement in the performance of the connectivity probability when increasing the number of the deployed Fixed-Femtos in a Macrocell. However, this has led to interference and unnecessary number of HOs.

While in the case of Mobile BSs, the authors in (Chae et al., 2013) presented a "novel HO scheme" that is utilising the coordinated multipoint transmission (CoMP) in high-speed moving vehicular Femtocell networks. The proposed scheme was aspiring for a seamless, deployable and efficient HO procedure for group of Mobile-Femtos that are installed in trains especially when the train changes its point of attachment.

The result of unsuccessful HOs has an impact on the probability of link outage. In (Sui et al., 2012), the authors investigated the power outage probability of vehicular UEs who are served by half-duplex decode-and-forward Relay Nodes (RN) under co-channel interference. In this study, Fixed RN showed its advantage in serving its nearby vehicular UEs while the moving RN showed a better quality of connection in terms of those vehicular UEs. While, in (Pan et al., 2015), the authors proposed an efficient HO scheme, which contained two procedures in order to mitigate the signal outage probability of vehicular UEs. The first procedure was an enhanced measurement procedure that accelerates the measurement procedure when the mobile RN knows that the train is moving toward some neighbouring DeNBs. While the second procedure was a group in-network HO procedure, where the entire installed mobile RNs in the train will be grouped and handed over between Macrocells.

In (Elkourdi et al., 2011), the authors evaluated the performance advantage of using Femtocells as Relays. The proposed approach enabled cooperative strategies between Home BSs and Macrocell BSs in order to mitigate the signal outage probability of vehicular UEs. While in (Haider et al., 2011), the authors investigated the effects of using mobile Femtocells in vehicles, specifically on the amount of signalling overhead between mobile Femtocells and Macrocells. The results showed large saving in the volume of signalling control when using mobile Femtocells to communicate with the eNB on behalf of the onboard mobile UEs. This has its own positive impact on improving the signals inside vehicles. Whereas, other studies like (Chowdhury et al., 2011) showed more trend towards the need of deploying Femtocells inside vehicles to improve the signal quality and uplink throughput.

It is quite noticeable that most of the HO work tackled the HO of Pico-cells and Fixed-Femtos (Badri et al., 2013; Xenakis et al., 2012). Whereas, few studies like (Raheem et al., 2015) considered the Mobile-Femto HO as a research of interest. Additionally, the previous works have shown a limitation in term of the Mobile-Femtos HO procedure and the possibility of handing over these small vehicular BSs from one Macrocell to another. As a result, handing over the Mobile-Femto from one Macrocell to another is considered a key challenge due to many factors that need to take a place here, like the backhaul link adaptability between the Mobile-Femto and the target eNB, the availability of the PRBs in the target eNB and the speed/direction of the Mobile-Femto. Therefore, the next following section proposes the Mobile-Femto HO procedure and the group vehicular UEs HO process. The impact of the proposed HO scheme on the reduction of the outage probability, dropping calls and blocking calls probabilities will be also tackled together with the increased traffic, number of channels and calls duration in comparison with the direct transmission from the eNB and the Fixed-Femto.

THE PROPOSED HO PROCEDURE

A major consequence of the objective of offering seamless HOs in LTE and LTE-Advanced systems is the data forwarded from the Source eNB (SeNB) to the Target eNB (TeNB). This forwarding of data typically takes place over the (wired) X2 interface between the eNBs (otherwise via the S1 interface). In the presence of Mobile-Femto deployments, this paper discusses a challenging HO scenario which is handing-over the Mobile-Femto itself from one eNB to another and forwarding the Mobile-Femto packets from the serving eNB to the target eNB. This HO scenario occurs when the Mobile-Femto moves away from one Macrocell towards another Macrocell based on the bus path as Figure 2 shows in the Appendix section.

In the above scenario, whenever the signal strength (SINR) between the Mobile-Femto and the source eNB goes down, the Mobile-Femto initiates a HO procedure in order to be handed-over to the neighbouring eNBs based on the Mobile-Femto direction (bus path). But, if the available PRBs in the TeNB are not enough to accommodate the coming Mobile-Femto, the Call Admission Control (CAC) allows the release of some BW from the existing direct links of Macro UEs by degrading their QoS level. The CAC policy will permit the reduction of the required BW for the Mobile-Femto request, which means that the system allows a maximum (BW_{eNB} - $BW_{min\text{-}required}$) amount of BW reduction for an existing Mobile-Femto. Hence, handing-over the Mobile-Femto to the target Macrocell, after finding

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the required PRBs, will be accompanied by a group UEs HO procedure for all those UEs inside the bus who are being served by the Mobile-Femto that is installed in the same bus as Figure 3 shows in the Appendix section. It is to be emphasised that the CAC is such a provisioning strategy to limit the number of call connections into the network in order to reduce the network congestion and call dropping.

On the other hand, if the $BW_{min\text{-}required}$ is not available in the TeNB after releasing some of the BW from the existing direct links of Macro UEs, the Mobile-Femto will not be connected to the TeNB and the UEs calls will be dropped. This due is to the lack of a sufficient number of PRBs to accommodate the coming Mobile-Femto and its UEs.

The following represents the HO process of handing-over the Mobile-Femto from the SeNB to the TeNB when the required BW is available in the target eNB to accommodate the coming Mobile-Femto and its UEs. During the Mobile-Femto HO process, several procedures are needed to be done sequentially in order to maximise the HO success probability in LTE and 5G vehicular networks. These procedures have been classified into five phases as Figure 4 shows in the Appendix section. It is to be mentioned that, the Serving DeNB (S-DeNB) configures and triggers the Mobile-Femto measurement procedure and then the Mobile-Femto sends a measurement report to the S-DeNB, includes the eNB ID of the Target DeNB (T-DeNB). Afterwards, the following phases occur:

1) HO decision phase: In this phase, the S-DeNB makes HO decisions based on the measurement reports of the Mobile-Femto. If the S-DeNB decides that the Mobile-Femto has to perform HO, the S-DeNB sends a HO request command to the T-DeNB including the necessary information to prepare the Mobile-Femto HO at the T-DeNB. This information may include S1/X2 signalling references and E-UTRAN Radio Access Bearer (E-RAB) attributes for Mobile-Femto. Necessary Radio Network Layer (RNL) and Transport Network Layer (TNL) information to the Mobile-Femto should also be passed to T-DeNB to ensure connectivity. The T-DeNB then performs the admission control dependent on the transmitted E-RAB attributes of the Mobile-Femto to decide whether to accept the Mobile-Femto or not. If yes, the T-DeNB replies a HO request Acknowledgment (ACK) to the S-DeNB after configuring/reserving the necessary resources for the Mobile-Femto operation. This ACK message includes RNL/TNL information for data forwarding of the Mobile-Femto and necessary security information of T-DeNB to the considered Mobile-Femto. Then, the S-DeNB informs the Mobile-Femto to handover by a Radio Resource Control (RRC) connection reconfiguration command.

2) Synchronization phase: After receiving the RRC connection reconfiguration command, the Mobile-Femto applies those configurations carried in the command. These RRC commands contain the necessary information for backhaul reconfiguration of Mobile-Femto towards the T-DeNB. Note that the necessary RRC information used in this phase is new and specific to the Un-interface (i.e. different from the RRC configuration messages exchanged during the HO of a regular UE, as the considered HO here is handing-over a BS). Then, the Mobile-Femto will try to synchronise with the T-DeNB by sending a preamble message. In the meantime, the S-DeNB sends a status transfer command to the T-DeNB to convey the Packet Data Convergence Control (PDCP) SNR receiver status for Uplink (UL) and Downlink (DL) of the Mobile-Femto in order to ensure the sequence of data forwarding of the Mobile-Femto Service Data Units (SDUs) from the S-DeNB to the T-DeNB. Additionally, in this phase the Mobile-Femto performs backhaul reconfiguration to the T-DeNB and access to the resources signalled previously in the RRC message. When compared to a regular UE HO, no Random Access Channel (RACH) procedure is needed in this case. On the UL the data of the UEs is buffered in the Mobile-Femto, while on the DL the incoming data for Mobile-Femto is forwarded by the S-DeNB to the T-DeNB and buffered in the T-DeNB. When the Mobile-Femto successfully connects to the target DeNB, the Mobile-Femto sends RRC message to the T-DeNB to confirm HO and T-DeNB begins to send DL data to Mobile-Femto.

3) Tracking area update phase: If successfully synchronised with the T-DeNB, the Mobile-Femto sends a tracking area update command to its MME. After receiving the command, the MME updates the Mobile-Femto's location. Then, the MME replies a tracking area update accept command to the Mobile-Femto to finish this phase.

4) Path switch phase: In this phase, the T-DeNB switches the routing path to the Mobile-Femto by sending a path switch request command to the MME. Then, the MME of the Mobile-Femto issues a UE plane update request command to the S-GW of the Mobile-Femto to switch the routing path. After finishing path switch, the S-GW replies a UE plane update response command to the MME, and then, the MME of the Mobile-Femto sends a path switch request ACK to the T-DeNB.

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5) S1/X2 and OAM phase: In this phase, the Mobile-Femto updates its registration information by the configurations from the Operations, Administration and Maintenance (OAM) server. The Mobile-Femto also requests the T-DeNB to reconfigure S1/X2 connections toward the S-GW and MME. After the given procedures, the T-DeNB and S-GW can forward data along the new routing path to the Mobile-Femto, and the in-network HO procedure ends.

In this HO process, the UE plane for UEs connected to the Mobile-Femto and the corresponding path switch are naturally grouped in the S/P-GW of the Mobile-Femto. This allows a group HO procedure of UEs plane during the Mobile-Femto mobility. However, if the T-DeNB does not have enough resources to accommodate the coming Mobile-Femto, it can reject all UEs attached to it, thus drops their calls.

On the other hand, there is always a possibility of PRBs shortage when trying to handover a Mobile-Femto to the neighbouring Macrocell. This shortage can occur when there are overlapped Mobile-Femtos at the same T-DeNB or when the T-DeNB is under heavy traffic load. This is because the traffic movement in streets is unpredictable especially for buses and cars and this may affect the HO procedure of Mobile-Femtos from one Macrocell to another. Consequently, the following scenario is considered as the worst-case scenario as the high volume of traffic is the main issue here. For example, when there is a Mobile-Femto moving out of the coverage area of the S-DeNB towards the coverage area of the T-DeNB while the required number of PRBs is inadequate to accommodate the coming Mobile-Femto with its UEs, the connection will be dropped, only when the number of required PRBs is available, then a connection will be established. Therefore, to maintain the vehicular UEs connection inside buses, those UEs can be served by the T-DeNB, by any nearby Fixed-Femtos or by any nearby Mobile-Femtos on another bus as Figure 5 shows in the Appendix section. However, this connection might not last long enough to continue serving those vehicular UEs. It might not even last more than few moments depending on those vehicular UEs speed and direction – basically, the bus speed and direction.

However, when the Mobile-Femto connection drops down, those vehicular UEs inside the bus will be considered as new UEs and they can establish a connection with any close by BS. Hence, the CAC initially checks whether the Mobile-Femto coverage in the same bus is still available or not. If it is available, then the Mobile-Femto is the first choice to connect the UE to; otherwise, other options are needed to be looked for. This means, the UE will try to connect with the T-DeNB. The T-DeNB does not allow the QoS degradation policy to accept any new UE and this UE will be rejected if the requested BW is not available. Afterwards, if both the Mobile-Femto and the T-DeNB coverage are not available, then the UE will try to connect to any nearby Fixed-Femto. Coverage and BW checks will be done and if any is not available then a worst-case solution comes here which is trying to connect to any nearby Mobile-Femto. However, if the last is not available too then the call will be blocked as Figure 6 shows in the Appendix section.

After discussing the worst-case scenario, here it is important to discuss the Macro UE HO procedure when this UE is already been connected to the eNB and needs a connection enhancement to overcome the high path and penetration losses inside vehicles. In this case, whenever the UE enters the bus, it can sense the Mobile-Femto SINR. The CAC policy checks the received SINR level of the target Mobile-Femto ($SINR_{TMF}$) compared to the eNB received SINR ($SINR_{eNB}$). Thus, the Macro-UE will be handed-over to the target Mobile-Femto when the current received $SINR_{eNB}$ level is less than or equal to the received $SINR_{TMF.}$ If any of the above conditions is satisfied, then a PRBs check in the target Mobile-Femto will be done as shown in Figure 7 in the Appendix section.

Hence, Algorithm 1 in the Appendix section represents the HO procedure between the Macrocell and the Mobile-Femto to improve the vehicular UEs performance and overcome the high path-loss and penetration loss issues. While the Fixed-Femto is always seen as an option when the Mobile-Femto coverage is not available to improve the Macro UE's signal quality.

Thus, after discussing the importance of the HO procedure in Mobile-Femto technology, now it is essential to evaluate the impact of handing-over the vehicular UE (bus passenger) to be attached and served by the installed Mobile-Femto in the same bus. The performance has been evaluated based on the signal outage probability, DCP, BCP and Link Ergodic capacity in LTE vehicular networks.

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SYSTEM MODEL

In the presence of fading, VPL and path-loss, there is always a probability that the received SINR at the receiver is below a given threshold to support a required transmission rate of R bits/sec/Hz. This is because all types of services have some minimum bit error rate requirements. These requirements can be translated to the minimum required average of the received SINR at the receiver. Based on what has been illustrated earlier, the probability that the received SINR falls below a given SINR threshold is referred to an outage probability. Nowadays, systems try always to keep this probability as low as possible to improve their network performance by especially improving their vehicular UEs connections.

Therefore, the outage probability has been analysed in term of the Fixed-Femto and Mobile-Femto assisted-transmissions in LTE Macrocell network.

Figure 8 in the Appendix section represents the HO possibilities that a vehicular UE can process to send and receive data or calls efficiently. Obviously, the highlighted vehicular UE has three BS options to be attached to as all the three BSs are in short range. Nevertheless, in this case the VPL plays a significant role in choosing the right BS. Besides that, the outage probability in this case is considered as an important factor that can easily affect the vehicular UEs signals, connections and performance. It is required here to calculate the outage probability of the vehicular UE in three cases; when this UE is connected directly with either the eNB, the Fixed-Femto or the Mobile-Femto. Having high outage probability means that the vehicular UE has made the wrong choice of connection with one of surrounding BSs. Hence, the outage probability of a single-hop system, when there is a direct transmission from the eNB to the vehicular UE, can be given by

$$\mathrm{P_{out\_D}}(\mathrm{SINR_{th\_D}}) = \Pr\left(\mathrm{SINR_{R_x}} < \mathrm{SINR_{th\_D}}\right) \quad \textbf{(1)}$$

Where the $SINR_{Rx}$ represents the instantaneous received SINR at the receiver R_x and P_r is the received signal power at the R_x (Goldsmith, 2005). The $SINR_{th\_D}$ is the required SINR threshold at the receiver R_x to support a given target rate over the direct link between the eNB and the vehicular UE. While the threshold here is a system design parameter and depends on several factors such as the achievable target rate of an LTE system. It is worth noting that the signal will be outage when the received SINR at the receiver side is below the given SINR threshold. This has its negative impact on the achieved system performance especially when UEs feel that they are not getting the best services they are paying for. Hence, the SINR threshold in the case of direct transmission when a rate of R bits/sec/Hz is required at the vehicular UE's end, can be given by

$$\mathrm{SINR_{th\_D}} = \mathrm{SINR_{th\_femto}} = 2^{\mathrm{R}} - 1 \quad \textbf{(2)}$$

Femtocells are using the full duplex transmission mode like the eNB and this is why in Femtocell-assisted system, both the backhaul and the access links are supporting a given end-to-end rate of R bits/sec/Hz at the receiver R_x, thus the same SINR threshold is used for both.
However, if the transmitter T_x has an average transmission power of P_x and the receiver R_x is at distance y from the transmitter T_x, the Pr at R_x can be given by

$$\mathrm{P_r}(\mathrm{y}) = \mathrm{P_x}\mathrm{L}(\mathrm{y})\psi|\mathrm{G}|^2 \quad \textbf{(3)}$$

Here, L(y) models the path-loss when the receiver R_x is at distance y from the transmitter T_x, while ψ is equal to the constant loss (C) of the free space path-loss model which is -84dB according to (Masui et al., 2002). On the other hand, G here represents the channel complex gain. Whilst the threshold $SINR_{th\_D}$ or $SINR_{th\_femto}$ varies according to different QoS requirements like the achievable rate of an LTE system, which is in turn based on Shannon capacity that can be given by the following

$$\mathrm{R(bits/sec/Hz)} = \mathrm{BW_{eff}}\log_2(1 + \mathrm{SINR_{eff}}) \quad \textbf{(4)}$$

Where BW_{eff} adjusts for the BW efficiency and $SINR_{eff}$ denotes the SINR implementation efficiency of the system as shown in (Mogensen et al., 2007). The SINR has been considered here instead of the SNR because of the existence of the interference issue in this case. This is due to the multiple access method, since several transmitters

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can send information simultaneously over a single communication channel. This allows several UEs to share a band of frequencies, which may cause interference between UEs. Thus, the $SINR_{th\_D}$ and $SINR_{th\_femto}$ can be obtained with a required end-to-end rate of R bits/sec/Hz for direct, backhaul and access links transmission as the following

$$\mathrm{SINR_{th\_D}} = \mathrm{SINR_{th\_femto}} = (2^{R/BW_{eff}} - 1) \quad \textbf{(5)}$$

Thus, after calculating all the required parameters, it becomes now easier to find out the outage probability of Mobile-Femto and Fixed-Femto assisted transmissions. In Mobile-Femto assisted system, the access link is not corrupted or affected by the multipath fading due to the short distance between the UE and the serving Mobile-Femto. In this case, the outage probability can be obtained similarly to the single-hop system of direct transmission with the use of the $\mathrm{SINR_{th\_femto}}$. While, the P_r value will be different from the direct transmission P_r and this is because in the case of Mobile-Femto the channel complex gain has been removed due to the short distance between the receiver and the transmitter as well as there is not penetration loss between the two. Hence, the Mobile-Femto assisted-transmission P_r can be obtained by

$$P_r(y) = P_x^{MFemto} PL(y)\psi \quad \textbf{(6)}$$

Where here the PL(y)ψ is equal to the constant loss (C) of the free space path-loss model. On the other hand, the outage may occur if either the backhaul or the access link is outage in the case of the Fixed-Femto assisted system as the following

$$P_{out_{FF}}\left(\mathrm{SINR_{th_{femto}}}\right) = \Pr\left(\min(\mathrm{SINR_{backhaul}}, \mathrm{SINR_{access}}) < \mathrm{SINR_{th\_femto}}\right) \quad \textbf{(7)}$$

Hence, if the value of the achieved outage probability is high, so the number of dropped calls is high too. Several elements play an important role in DCP and the strength of received power over distance such as the path-loss, penetration loss and shadowing. The path-loss is caused by dissipation of power radiated by the transmitter as well as effects of the propagation channel. While shadowing is caused by obstacles between the transmitter and receiver that absorb power, which is known also as the penetration loss. However, when the obstacle absorbs all the power, the signal is blocked and this is what happens for vehicular UEs in public transportations. The variation due to the path-loss occurs over very large distances, whereas variation due to shadowing occurs over distances proportional to the length of the obstructing objects, which might be buildings or even the chassis of vehicles. On the other hand, it is worth noting that the used path-loss model (in dB) in this work is the Microcell NLOS path-loss model, which is based on the COST 231 Walfish-Ikegami NLOS model and can be given by the following

$$PL(L) = 34.53 + 38\log_{10}(L) \quad \textbf{(8)}$$

Where L is the distance from the transmitter T_x to the receiver R_x.

However, in wireless systems there is typically a target minimum received power level P_{min} below which performance becomes unacceptable. As a result, the DCP(P_{min}, L) under path-loss and shadowing is the probability that the received power at a given distance d, Pr(L), falls below P_{min} which can be given by

$$DCP(P_{min}, L) = P(P_r(L) < P_{min}) \quad \textbf{(9)}$$

While the BCP occurs when there is a shortage with the availability of the required number of channels to accommodate the new coming UE into the Macrocell and this happens in high-traffic areas. Therefore, the BCP can be calculated as

$$BCP(A, N_{ch}) = \frac{\frac{A^N}{N!}}{\sum_{i=0}^{N}\frac{A^i}{i!}} \quad \textbf{(10)}$$

Where A is the successive call time arrivals and N is the number of channels in the system. Furthermore, A is the traffic stated in Erlang and can be given by

$$A = \lambda t_h \quad \textbf{(11)}$$

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In which λ represents the call arrival rate per second and t_h is the call holding time of UEs per second.
It has become obvious now that there are many factors influencing the drop and block calls probabilities like the signal received power and the channel availability to accommodate the coming calls. Other indirect factors have huge impact on increasing any of the previous probabilities like the path-loss, penetration loss, shadowing and the heavy load traffic. Therefore, it was needed to deploy the Mobile-Femtos in public transportation to improve the vehicular UEs performance and reduce the DCP (Raheem et al., 2014).
Hence, based on figure (8) and Shannon Theorem now it becomes necessary to state the Ergodic capacity of direct, backhaul and access links that are generally can be given by

$$C_{b,d,a} = [\min\{C_{backhaul}, C_{direct}, C_{access}\}] \quad \textbf{(12)}$$

The backhaul links between the eNB-Fixed Femtos and the eNB-Mobile Femtos are assumed to be NLOS outdoor links. As a result, the backhaul link capacity between the eNB and the Fixed-Femto at distance *d* can be given by

$$C_{backhaul(eNB-FixedFemto)} = BW_{eNB-FixedFemto} \log_2\left(1+\frac{P_x^{eNB}|G_1|^2\, PL(d)}{P_{noise}}\right) \quad \textbf{(13)}$$

While the backhaul link capacity between the eNB and the Mobile-Femto at distance *x* can be given by

$$C_{backhaul(eNB-MobileFemto)} = BW_{eNB-MobileFemto} \log_2\left(1+\frac{P_x^{eNB}|G_1|^2\, PL(x)}{P_{noise}}\right) \quad \textbf{(14)}$$

It should be noticed that, in the backhaul link capacity between the eNB and the Mobile-Femto there is a small channel gain like the Fixed-Femto due to the distance gap between the Mobile-Femto and the eNB as well as the NLOS backhaul link. While, the $C_{direct(eNB\text{-}UE)}$ can be given as the same as the $C_{backhaul(eNB\text{-}Mobile\text{-}Femto)}$ in equation (14), since the direct link between the eNB and the vehicular UEs is a NLOS link and the distance between the eNB and the UE is the same as the distance between the eNB and the Mobile-Femto.

Hence, based on the above equations, the access link capacity between the Fixed-Femto and the vehicular UE at distance *x-d* can be derived and given as

$$C_{access(FFemto-UE)} = BW_{FixedFemto-UE} \log_2\left(1+\frac{P_x^{FFemto}|G_2|^2\, PL(x-d)\, \varepsilon}{P_{noise}}\right) \quad \textbf{(15)}$$

While the access link capacity between the Mobile-Femto and the vehicular UE is a special case scenario as the penetration loss is equal to zero. This is because there are no boundaries between the UEs and the serving BS so nothing resists the signal from reaching the UEs without losses. As a result, an LOS access link and a constant power loss C_{loss} = -84dB have been assumed (Masui et al., 2002). Therefore, the link capacity can be given by

$$C_{access(MFemto-UE)} = BW_{MobileFemto-UE} \log_2\left(1+\frac{P_x^{MFemto} C_{loss}}{P_{noise}}\right) \quad \textbf{(16)}$$

Here the $BW_{eNB\text{-}FixedFemto}$ and $BW_{eNB\text{-}MobileFemto}$ represent the bandwidth of backhaul links between eNB-FixedFemto, eNB-MobileFemto while $BW_{FixedFemto\text{-}UE}$ and $BW_{MobileFemto\text{-}UE}$ represent the bandwidth of access links between FixedFemto-UE and MobileFemto-UE respectively. Added to this, the P_x^{eNB}, P_x^{FFemto} and P_x^{MFemto} denote the average transmission power of the eNB, Fixed-Femto and Mobile-Femto while G_1 denotes the complex channel gain

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of the backhaul link and G_2 denotes the complex channel gain of the access link in the Fixed-Femto assisted transmission. While PL represents the used path-loss model.

RESULTS AND DISCUSSION

This section discusses the achieved results in term of vehicular UEs outage probability, DCP, BCP and Link Ergodic capacity. These achieved results create a comprehensive comparison between the signal quality of direct transmission from the eNB, Fixed-Femto and Mobile-Femto. In these results, three parameters play an important role in the achieved performance, which are the path-loss, the VPL and finally the signal shadowing.

Figure 9 in the Appendix section clearly shows the advantage of deploying the Mobile-Femto in LTE vehicular networks especially when the distance between the eNB and the vehicular UE is comparatively high. The signal level at the UE from the Mobile-Femto is almost the same because the distance between the UE and the Mobile-Femto is constant. In this case, the SINR is at its highest, which is 52dB while in the case of the Fixed-Femto transmission, the SINR shows a fluctuation with the path-loss changes. Another factor plays significant role in the SINR reduction, which is the LTE VPL that has been set to 25dB.

While Figure 10 in the Appendix section illustrates the uplink throughput comparison of vehicular UEs in LTE Macro-cellular network. The poor received signal from the eNB causes very small Uplink throughput compared to the Uplink throughput of UEs who are being served by the Mobile-Femto. This is due to the short distance between the vehicular UE and the installed Femtocell in the same bus. Also, in the case of the Mobile-Femto transmission, the received signal level at the receiver outside the vehicle, e.g. the bus, is comparatively acceptable for those UEs who are close to the bus. However, the connection with those outside the bus UEs might not last more than few moments depending on the bus's direction and speed. This represents the case when there are UEs on another bus close to a Mobile-Femto and they can get the advantage of this Mobile- Femto signal when they could not find enough channels and PRBs in their own Mobile-Femto. Those UEs connection might not last more than few moments and their calls will be dropped as long as the distance between the two parties increases.

After discussing the signal quality inside public transportation, it is important now to discuss the signal outage probability of those UEs who are inside these vehicles. In the outage probability scenarios, the Mobile-Femto is assumed to be installed in public transportations like buses, and fully circumvent the VPL while the Fixed-Femtos are assumed to be positioned in bus stations (bus stops) or at the side of the bus paths. Table 1 in the Appendix section gives detailed parameters of the simulated scenarios.

Figures 11, 12 and 13 in the appendix section demonstrate the Outage Probability under different VPL scales. The results show that, when the VPL is equal to 0dB, the direct transmission from the eNB always achieves the lowest outage probability since there is no resistance against the transmitted signal. While at 400m distance from the BS, the vehicular UEs who are being served by the Fixed-Femto achieved lower outage probability than the Mobile-Femto UEs. This is because when there is no penetration loss, the Fixed-Femto signal can travel smoothly without massive reduction in the received power (P_r) at the vehicular UE's end. Besides that, the mobility aspect of the Mobile-Femto creates link variation in the backhaul link between the eNB and the serving Mobile-Femto, which becomes obvious compared to the other BSs transmissions with the absence of the VPL.

While in Figures 12, the outage probability of the Mobile-Femto assisted-transmission at a VPL of 25dB is always lower than the outage probability of the direct transmission and the Fixed-Femto assisted-transmission. This indicates that the Mobile-Femto assisted system is better at maintaining a given rate of R bps/Hz for a vehicular UE, which can be translated to a good QoS compared to the other two transmissions. However, with the increased distance -over 300m- the Fixed-Femto assisted-transmission starts to achieve lower outage probability compared to the direct transmission from the eNB and this is due to the high path-loss of the eNB signal over distance when it tries to reach the vehicular UEs inside vehicles. Here it raises the case of being able to be attached to any nearby Fixed-Femto when the Mobile-Femto channels and PRBs are fully occupied by other UEs. This might be a temporary solution to improve the vehicular UEs signal quality unless the required PRBs are available in the Mobile-Femto to accommodate those UEs. Otherwise, the connection will be dropped as soon the distance increases between the vehicular UE and the serving Fixed-Femto.

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As the VPL value goes up to 40dB, the Mobile-Femto assisted-transmission outperforms the direct transmission when the vehicular UE is fairly near the eNB (around 40m) as Figure 13 shows.

On the other hand, the Ergodic capacity of vehicular UEs' links plays an important role in evaluating their performance as it is significantly affected by the outage probability. Other factors can play important roles in the Links Ergodic capacity such as the VPL and the path-loss. Thus, Figure 14 in the Appendix section shows that when there is no VPL, the direct transmission always achieves the highest Ergodic capacity. Low VPL means low resistance against the transmitted signal without dramatic reduction in the signal's power.

On the other hand, as the VPL increases, both the Mobile-Femto and Fixed-Femto assisted-transmissions achieve higher link capacities especially when the vehicular UE moves away from the eNB.

Figure 15 in the Appendix section shows the Ergodic capacity when the VPL is equal to 25dB. At 500m distance from the eNB, the Mobile-Femto starts to achieve higher capacity. This is because with the increased penetration loss and path-loss, the Mobile-Femto in the bus is seeing as a better option for vehicular UEs to be connected to, and improve their throughput, subsequently their performance.

While in Figure 16 in the Appendix section, it is important to note that at a certain stage both of direct and Fixed-Femto transmissions Ergodic capacity will be poor as the VPL and the path-loss increase. At this stage, deploying Mobile-Femtos inside buses will be the enlightenment solution to overcome the signal reduction over distance.

However, high outage probability and low Links Ergodic capacity means high number of dropped and blocked calls. Hence, the achieved results in Figure 17 in the Appendix section reflect the fact that DCP has reduced when those UEs are being served by the Mobile-Femto rather than by the eNB or Fixed-Femto. This is because; the VPL of UEs inside public transportations makes it challengeable to maintain those UEs' connections from outside the vehicle. Also, the path-loss affects the signal power over distance L since the last makes the received signal at R_x much weaker than the minimum threshold P_{min} as in $(P_r(L) < P_{\min})$. However, the distance between the vehicular UE and the Mobile-Femto is very short. This means the $(P_r(L) > P_{\min})$, which reduces the number of dropped calls. The Mobile-Femto achieved less DCP when the distance between the UE and the eNB BS is less than 500 while it increases slowly until it reaches its max of 0.05 at 1000m. This is due to the backhaul link variation occurring when the Mobile-Femto moves away from the eNB and gets close to the edges of the Macrocell. A HO procedure is needed to be established with a neighbouring Macrocell to maintain the connection of this Mobile-Femto.

On the other hand, Figure 18 in the Appendix section illustrates the correlation between DCP and call duration. It shows that the call duration is another parameter that can affect the QoS in a cellular network. It is the time that a mobile station takes to complete a call connection, which has been given by $t_h = \frac{A}{\lambda}$. The call arrival rate varies with call duration the same way it varies with DCP. Hence, DCP decreases with the increase in call duration. In real life scenarios, it is noticeable that calls may last longer with the good quality connection. Thus, deploying Femtocells in public transportations like buses has improved the ability of UEs to make phone calls and being connected to the Internet while the bus is moving.

As path-loss and call duration play important roles in the degradation of the DCP, the channels availability has a significant role too. Channels availability does not affect only the probability of dropped calls but also the probability of blocked calls. This is because when new calls (new UEs) try to establish a connection with the target BS, the calls of those UEs can be blocked due to the non-availability of the required number of channels and PRBs to accommodated the new UEs.

Figure 19 in the Appendix section shows that with the increased number of channels, vehicular UEs experience less BCP in the case of the Mobile-Femto implementation. This is because vehicular UEs, do not need to establish a connection with far BSs when they can be connected to the Femtocell that is installed in the same bus. Moreover, the number of HOs can be reduced too as those UEs can have long connections with the installed Femtocell regardless of their continuous movement.

As mentioned earlier, the new calls will be blocked when the required number of channels is not available. No channels availability means the number of PRBs is not available to accommodate the upcoming new UEs to the cell. This can occur with the increased number of active UEs as more resources are required to accommodate the

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upcoming traffic. This issue increases in the case of vehicular UEs as they are more exposed to interference, high path-loss and high VPL, which can increase the burden on the eNB. Thus, implementing Mobile-Femtos can effectively improve those new vehicular UEs services. As a result, this can reduce the number of blocked calls since Mobile-Femtos can be reached easily by those vehicular UEs and they can enjoy better connection and services.

Figure 20 in the Appendix section shows that Fixed-Femto vehicular UEs experience the highest calls blocking probability at max 0.33 due to the vehicular UEs continuous movement that makes it hard for the new UEs to establish new connections without losing them after moments. On the other hand, Mobile-Femto assisted-transmission has achieved the lowest BCP at 0.2 due to the high SINR inside the vehicle.

CONCLUSION

This paper has proposed an efficient Mobile-Femto HO procedure. This HO procedure included grouped UEs HO process for all those vehicular UEs inside the bus. Previous works have shown that the number of HOs increases with the increased value of UEs speed as well as the number of unnecessary deployed small BSs. For those reasons, the outage probability and the UE's distance correlation has been evaluated under different VPL scales as well as the Link Ergodic capacity. This paper has also evaluated the impact of path-loss and call duration on the achieved DCP. While BCP has been evaluated in terms of channel availability and traffic intensity. The achieved results have shown that the number of dropped and blocked calls has been reduced after implementing the Mobile-Femtos in the Macrocell compared to the direct transmission from the eNB and the Fixed-Femtos.

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Appendix

Algorithm 1 Macro UE HO procedure

Algorithm 1: Macro UE HO procedure

detects Mobile-Femto SINR /* if available so do the following
initiate HO_ DReq /* send HO request to the Mobile-Femto
receive DReq from Macrocell of UE_u
if $*N_j < N_{jmax}$ & $BW_{MFemto\text{-}total} + BW_{required} < BW_{MFemto\text{-}max}$ ***then***
accept UE_u
$N_j = N_j + 1$
$BW_{MFemto\text{-}total} = BW_{MFemto\text{-}total} + BW_{requierd}$
  else if $N_j \geq N_{jmax}$ & $BW_{MFemto\text{-}total} + BW_{required} \geq BW_{MFemto\text{-}max}$ ***then***
    reject UE_u
  end
end
else Detects Fixed-Femto SINR /* if available so do the following
initiate HO_ DReq /* send HO request to the Fixed-Femto
receive DReq from Macrocell of UE_u
if $*N_i < N_{imax}$ & $BW_{FFemto\text{-}total} + BW_{required} < BW_{FFemto\text{-}max}$ ***then***
accept UE_u
$N_i = N_i + 1$
$BW_{FFemto\text{-}total} = BW_{FFemto\text{-}total} + BW_{requierd}$
  else if $N_i \geq N_{imax}$ & $BW_{FFemto\text{-}total} + BW_{required} \geq BW_{FFemto\text{-}max}$ ***then***
    reject UE_u
  end
end
if performance_degradates then
drop_call
end

***Nj and Ni represent the number of vehicular UEs in Mobile-Femto and Fixed-Femto respectively**

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Table 1 Detailed simulated parameters of the Outage Probability scenarios

Parameters			**Values**		
Schemes	Duplex Mode	Path-loss Model	UE Position Distribution	VPL (dB)	Transmission Power
Direct Transmission	Full Duplex	3GPP SCM Urban NLOS Microcell model	Uniform distribution	0, 25, 40	$P_x^{eNB} = 46$ dBm
Fixed-Femto assisted Transmission	Full Duplex	Urban SCM NLOS Microcell model for both backhaul and access links	Uniform distribution	0, 25, 40	$P_x^{eNB} = 46$ dBm and $P_x^{FFemto} = 24$ dBm
Mobile-Femto assisted Transmission	Full Duplex	Backhaul link: SCM urban NLOS Microcell model. Access link: Constant path-loss	Uniform distribution	0	$P_x^{eNB} = 46$ dBm and $P_x^{MFemto} = 24$ dBm
Path-loss Model in dB			$PL(L) = 34.53 + 38\log_{10}(L)$		
Cell Radius D			1000 m		
Receiver noise figure for both Femtocell and UE			9 dB		
Minimum required rate R at the UE			2 bits/sec		
Fading			Small-scale fading		

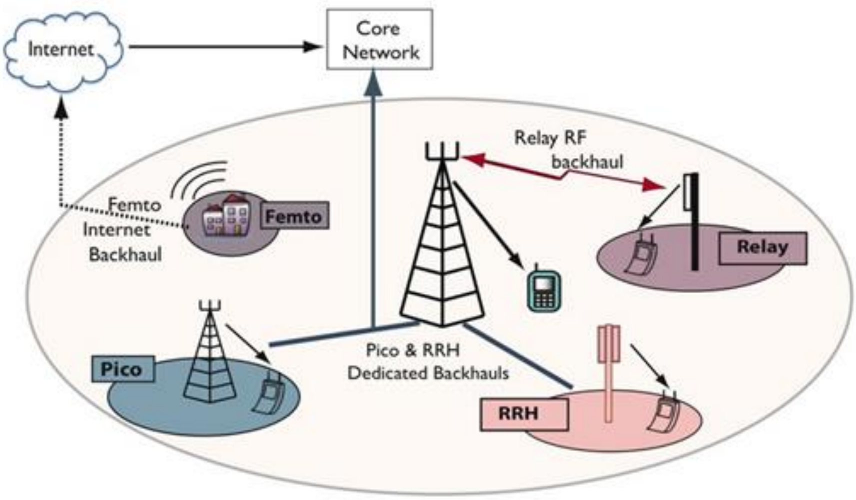

Figure 1 Heterogeneous networks

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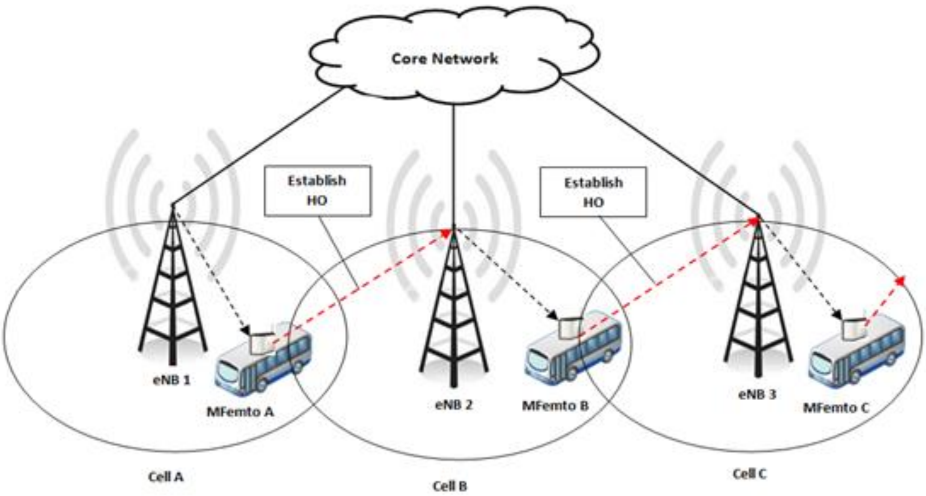

Figure 2 Handing over Mobile-Femtos between Macrocells

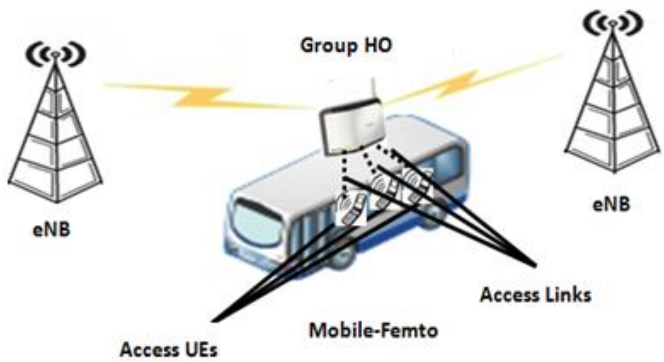

Figure 3 Group HO of Mobile-Femto UEs

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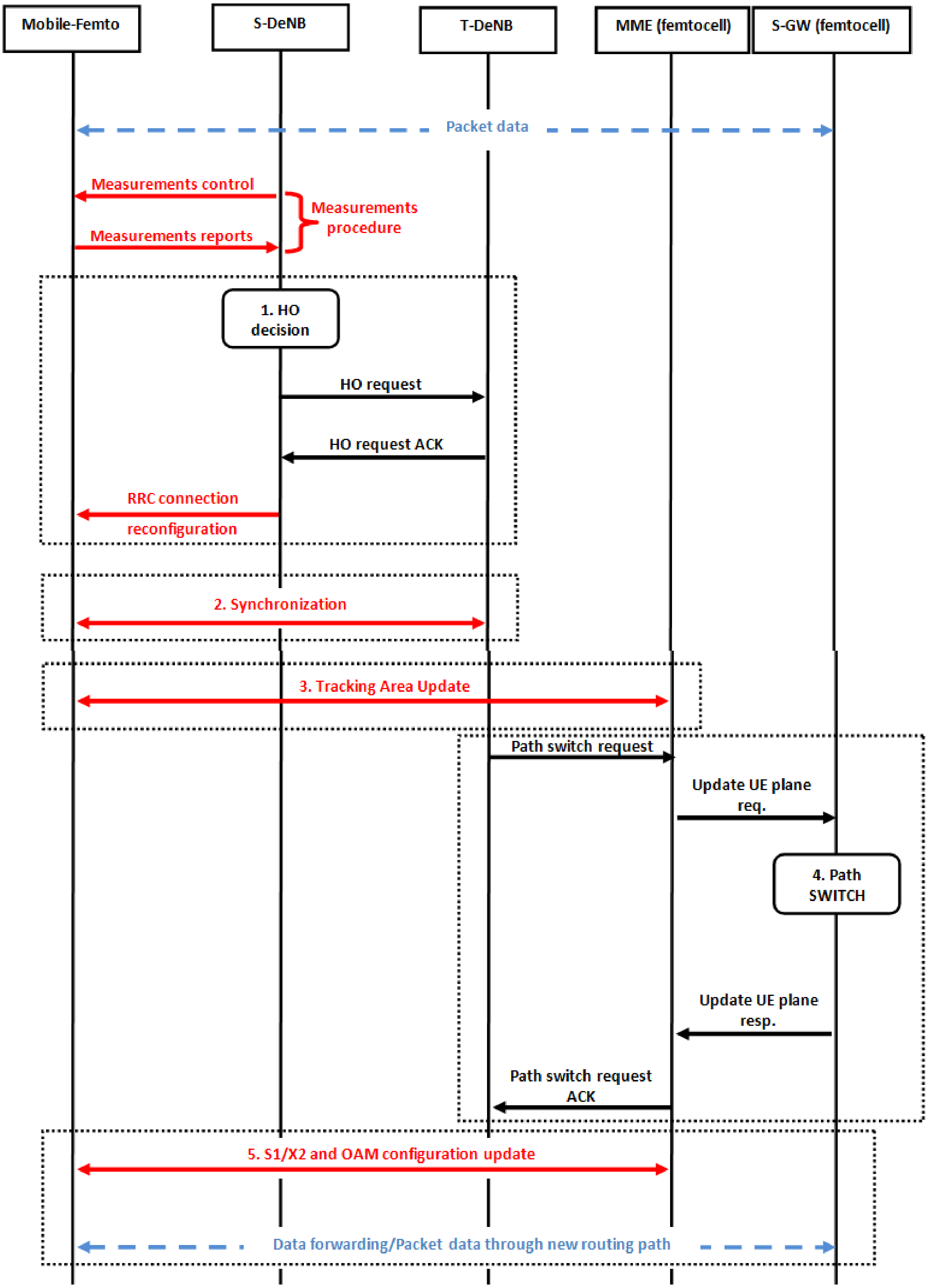

Figure 4 Mobile-Femtos HO from serving eNB to target eNB

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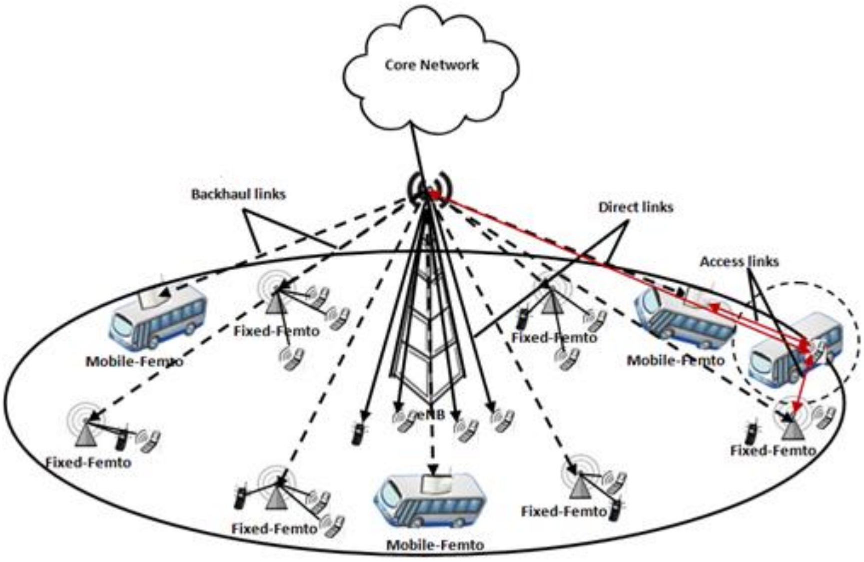

Figure 5 Connection establishment in the worst-case traffic

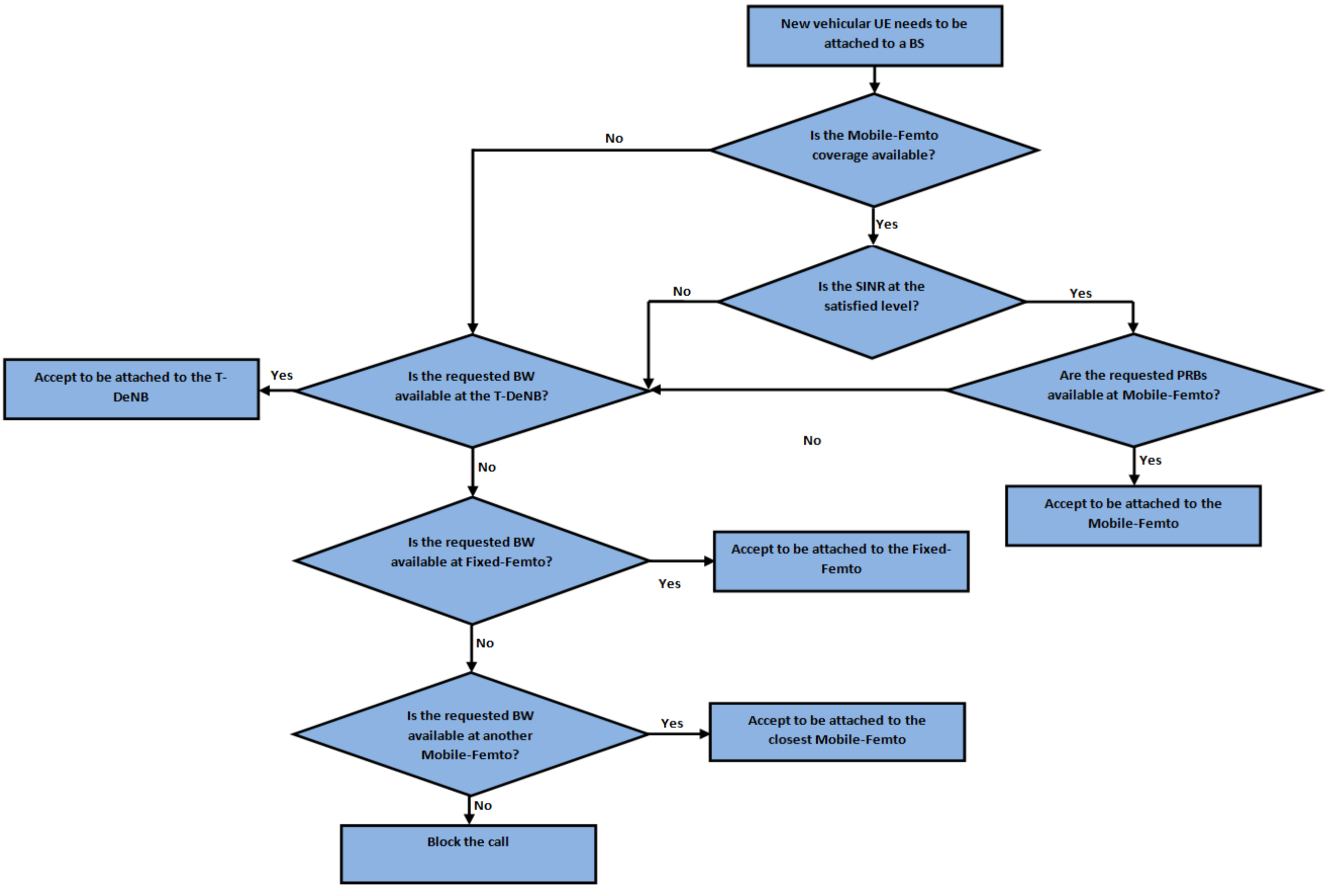

Figure 6 Connection establishment for new vehicular UEs

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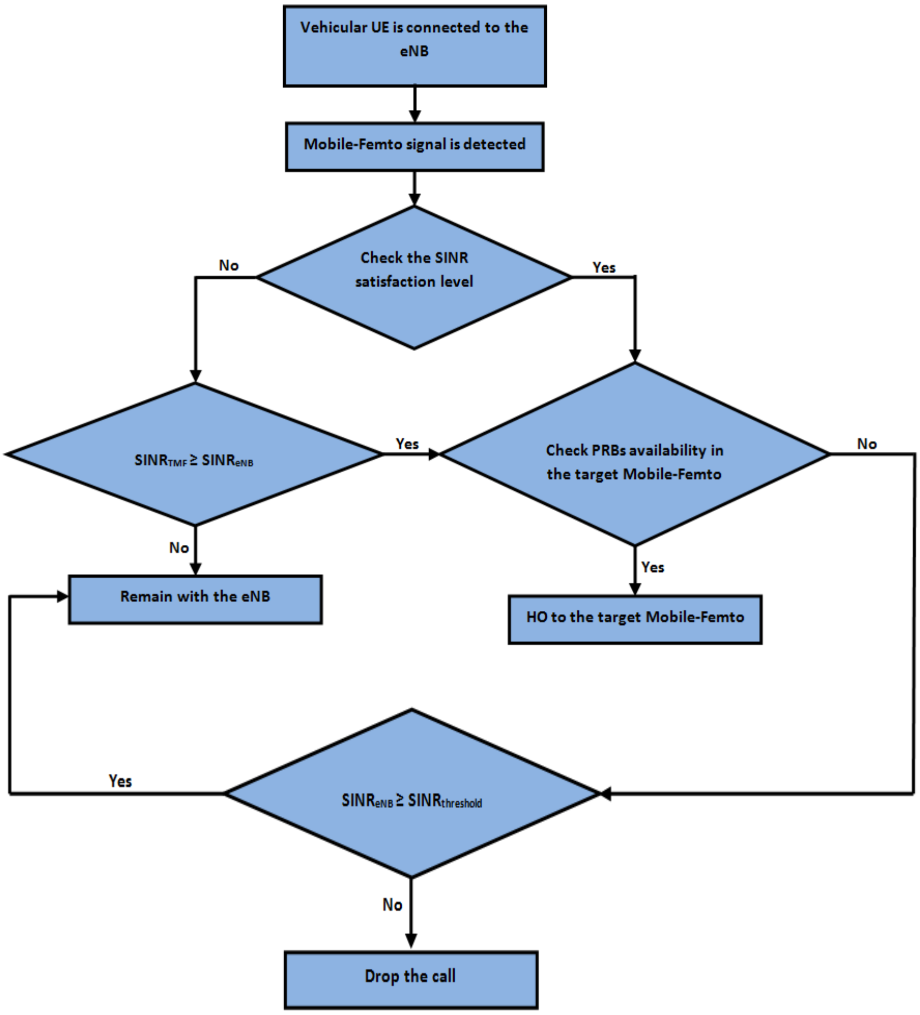

Figure 7 Vehicular UEs HO process from eNB to Mobile-Femto

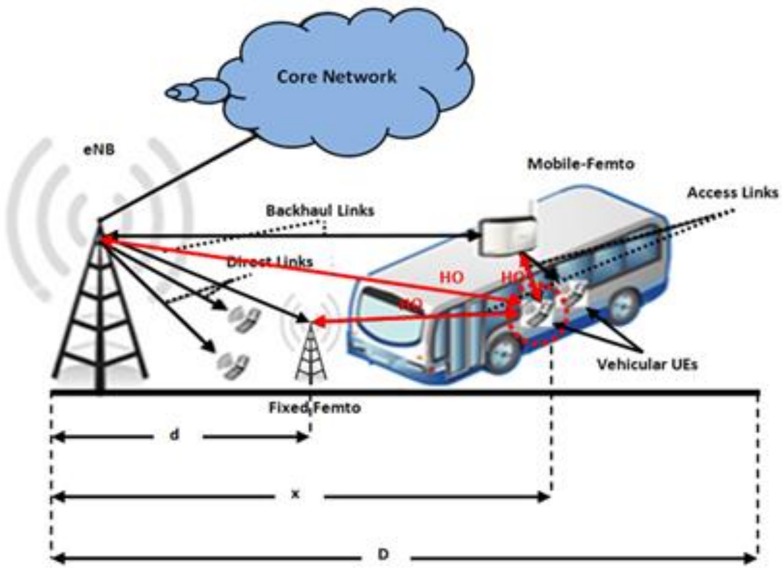

Figure 8 Vehicular UE connection probabilities

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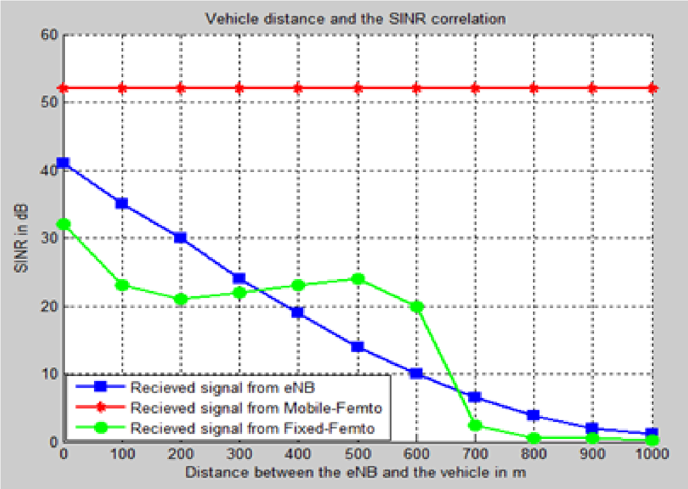

Figure 9 SINR received from eNB, Fixed-Femto and Mobile-Femto

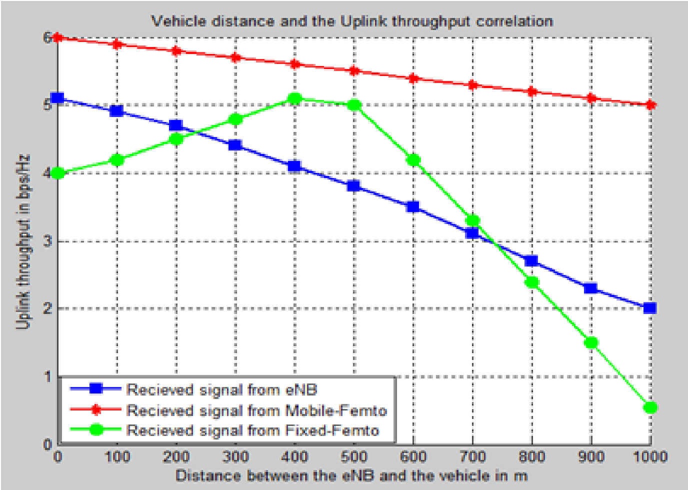

Figure 10 Uplink throughput of vehicular UE before and after deploying Femtocells

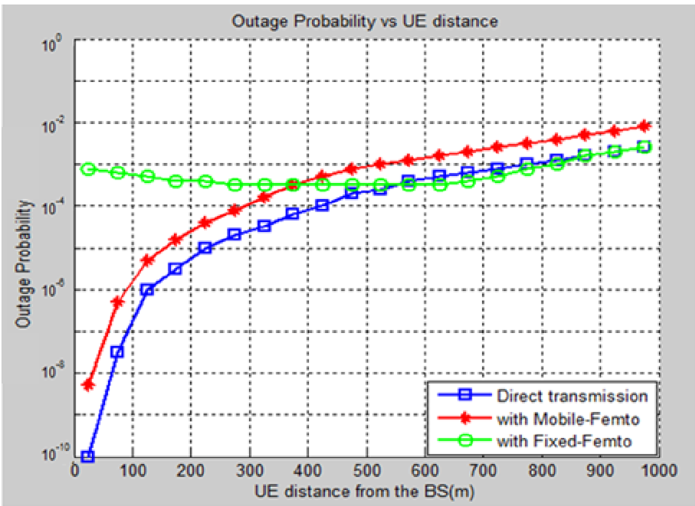

Figure 11 Outage Probability when the VPL= 0dB

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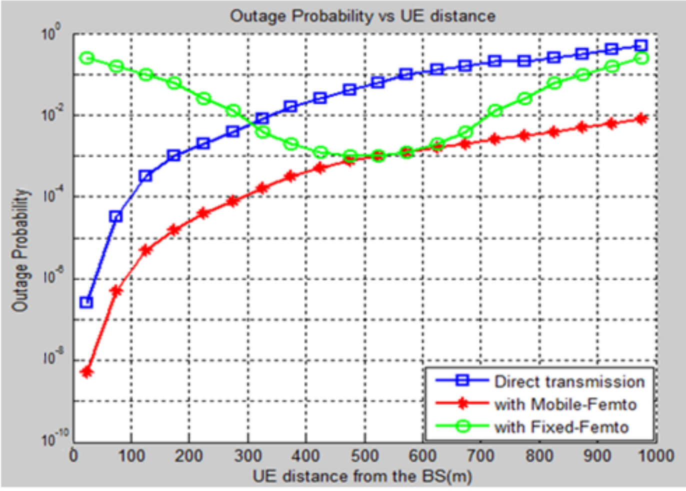

Figure 12 Outage Probability when the VPL= 25dB

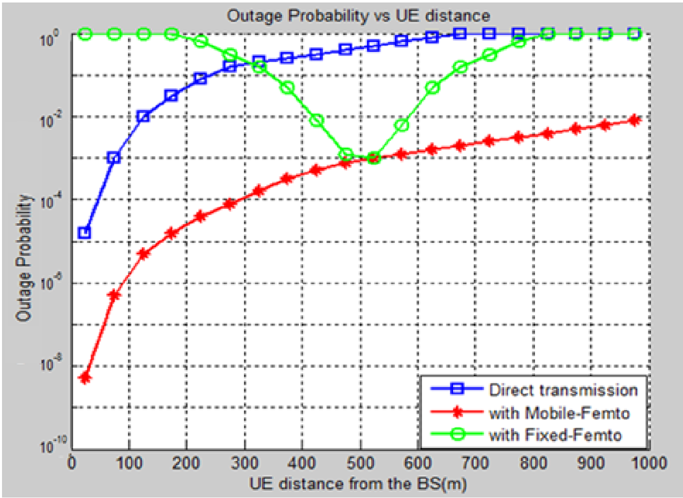

Figure 13 Outage Probability when the VPL= 40dB

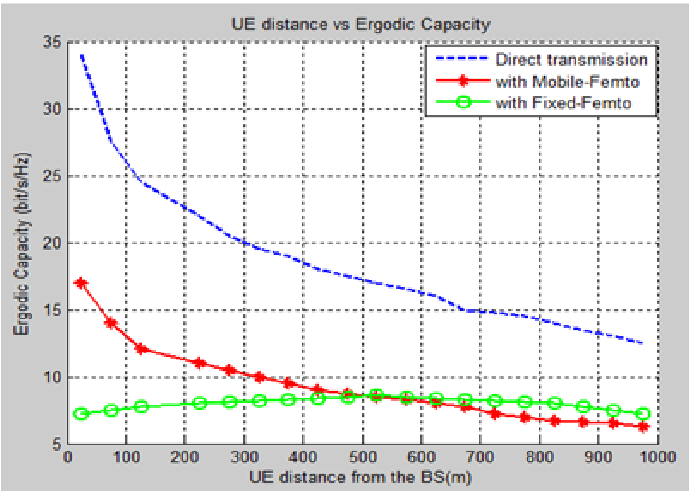

Figure 14 Link Ergodic Capacity when the VPL = 0dB

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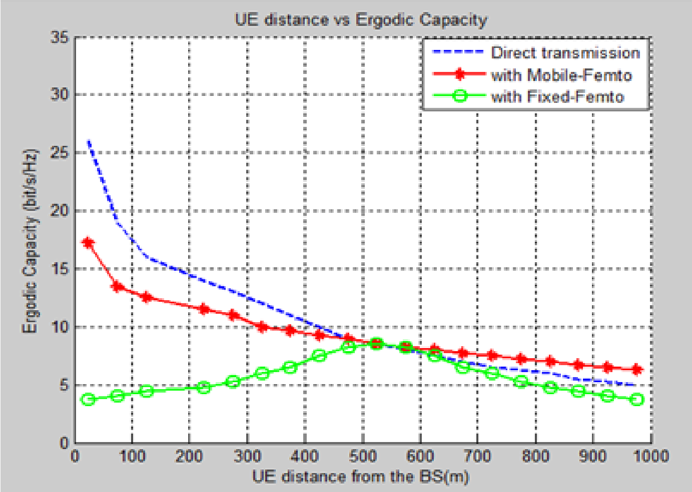

Figure 15 Link Ergodic Capacity when the VPL = 25dB

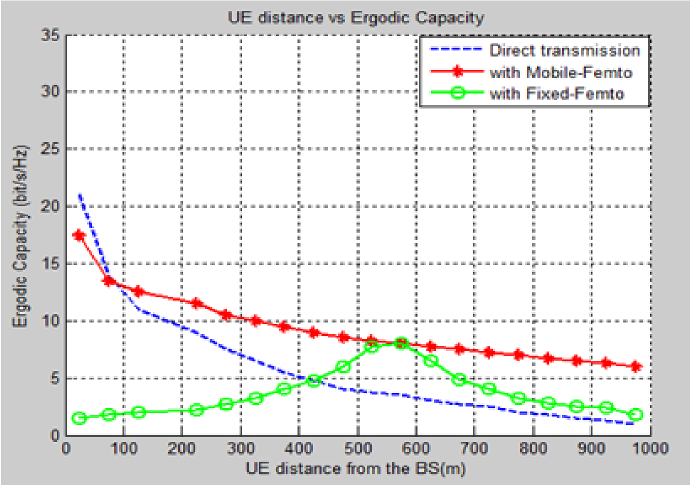

Figure 16 Link Ergodic Capacity when the VPL = 40dB

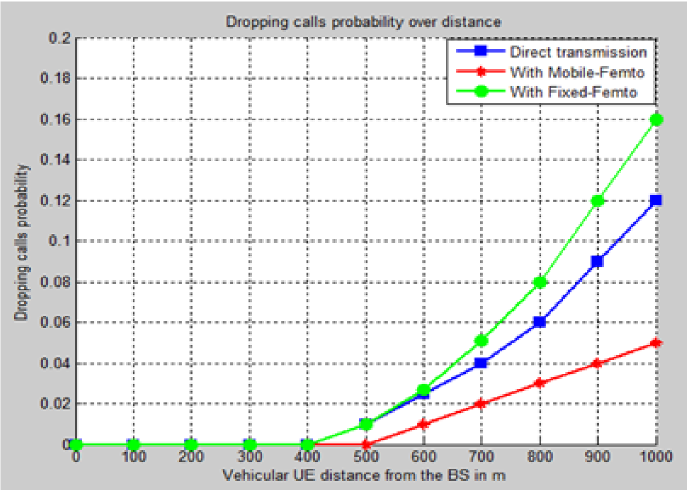

Figure 17 Drop Calls Probability vs. Distance from the BS

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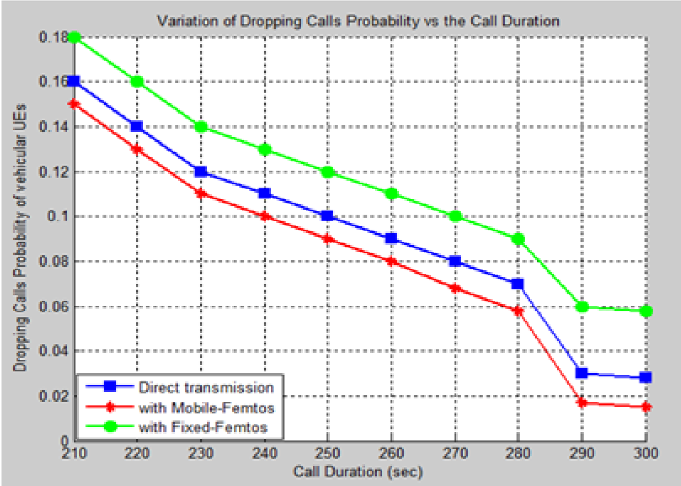

Figure 18 DCP vs. Call Duration

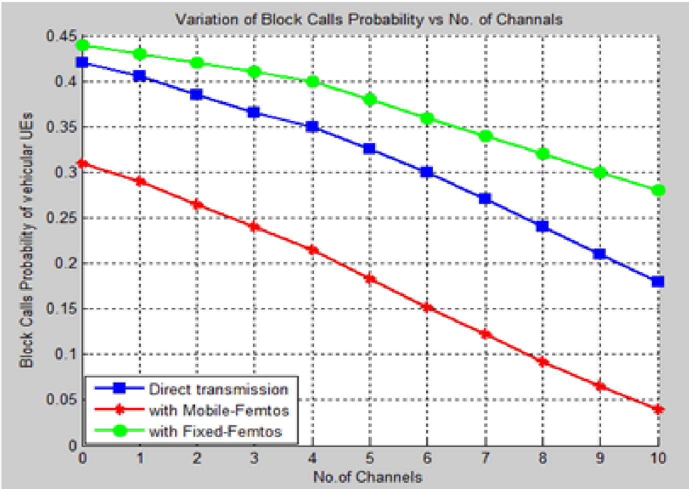

Figure 19 Block Calls Probability vs. No. of channels

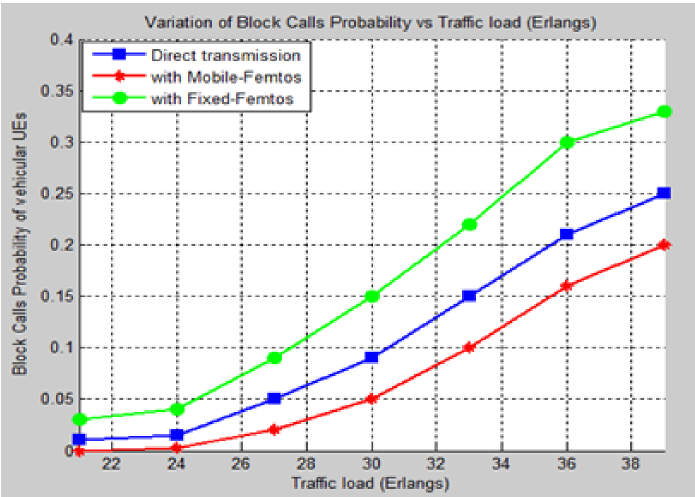

Figure 20 Block Call Probability vs. Traffic Load

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